

# 1

## DUAL-ADDRESSED RECTIFIER STORAGE DEVICE

### CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation in part of Application Ser. No. 08/610,992 entitled "Dual Addressed Rectifier Storage Device", filed Mar. 5, 1996, now U.S. Pat. No. 5,673,218, Sep 30, 1997.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to electronic data retrieval devices, and more particularly to electronic digital logic devices having semiconductor mass storage capabilities by virtue of their data being stored in highly symmetrical arrays of diodes.

#### 2. Prior Art

Most present day devices having mass storage capabilities rely on such moveable media as magnetic disks, optical compact disks, digital tape or the like. Some devices having large storage Capabilities have utilized large numbers of read-only memory (ROM) devices.

Many read-only memory (ROM) devices have been disclosed having a wide variety of implementations. In many of these devices the bit storage means is accomplished through the application of gates or transistors. But, a subset of these ROM devices has accomplished the bit, storage means through the use of a matrix of diodes, as was disclosed by Robb in U.S. Pat. No. 3,245,051. Many of these ROM device is include diode matrix storage means utilizing a set of conductors that act as selectors and a second orthogonal set of conductors that act as data outputs.

In U.S. Pat. No. 4,070,654, one set of generally parallel conductors acts as the Selection Input Lines and a second set of generally parallel conductors that is orthogonal to and overlapping with the first acts as the Digit Output Lines. A bit of information is represented at each point of intersection of the Selection Input lines with the Digit Output Lines by the presence or absence of a diode at that point, where the presence or absence of a diode distinguishes the logical state of the stored information bit at that point of intersection. A selection circuit selects one line of the Selection Input Lines such that the state of all of the Digit Output Lines is then controlled to the extent that each of those Digit Output Lines is connected to that selected Selection Input Line through a diode. All of the digit Output Lines are read in parallel. A disadvantage is that as the matrix is increased in size, the complexity of the selection logic that drives the selection circuits (such that one line is selected out of the many Selection Input Lines) grows exponentially. But as this matrix increases in size, so too will the number of Digit Output Lines that will have to be simultaneously supplied with current and that current will vary depending upon the state of the bits at those various locations. Also, as the number of simultaneously driven Digit Output Lines increases, some means of selecting the subset of desired data bits would have to be added.

In U.S. Pat. No. 4,661,927, some of the problems of the exponential growth in the complexity of the addressing circuitry and of the loading on the selected addressing lines are dealt with. Addressing is accomplished by using diode-transistor logic (DTL) for the input addressing. The transistors of the DTL selection circuits act as buffer-drivers between the address selection means and the bit storage

means thereby providing the current needed to source a growing number of data bit output lines. However, the transistors in this DTL circuitry add complexity to the overall circuit which will reduce packing densities and add an additional problem—that of leakage currents in those transistors—that requires additional compensating circuitry that further reduces packing densities. The use of dummy diode loads for balancing data dependent loading variations reduces packing densities even further.

In U.S. Pat. No. 4,884,238, the problem of loading is dealt with by utilizing FET switches to disconnect all but the desired Digit Output line. The selected bit is present at the intersection of two selected orthogonal conducting lines. In this way, the number of bits simultaneously selected does not grow with the size of the array and the problem of loading can be controlled. But, such a design still requires a large number of FET transistors and the addressing means to control those FET transistors and the interconnection wiring to connect said addressing means with said FET transistors which will reduce packing densities. While the addressing means could be of the same DTL type to keep said addressing means small, the large number of buffering transistors to select the various conductive lines will remain large (at least one FET per conductive line and, on about half of the lines, two FET's). Furthermore, this inclusion of FET transistors may make the device subject to damage from static electrical discharges that might make it less practical for use in a consumer product where the consumer may handle these devices.

In U.S. Pat. No. 4,347,585, Eardley discloses a dual-addressed device wherein the selected diode is at the intersection of a column line and a row line (where the column lines are connected to the diodes' cathodes and the row lines are connected to the diodes' anodes) such that the voltage potential of one column line is lowered and the voltage potential of one row line is raised thereby forward biasing the diode, if any, at the point of intersection of the two lines. One of the features of this device over the prior art (as discussed in that patent) is the circuitry for the selection logic; Eardley discloses means for line selection comprising high speed transistor driver circuits. The disclosed device also requires two types of Schottky barrier diode devices. As a result, it is anticipated that the disclosed device will suffer from several problems, particularly when one attempts to scale up the device to extremely high storage densities. These problems may include transistor current leakage becoming noticeable as the number of transistors increases and device yields becoming reduced as the complexity of multiple semiconductor fabrication steps and more complex device interconnect circuitry increases. These problems may prevent the kind of size scaling that could result in devices in the Gigabit range that would be necessary to create memory chips that could replace today's CD-ROMs.

As will be shown below, the Dual-addressed Rectifier Storage (DRS) Array comprised by the present invention solves many of the Problems associated with the above mentioned inventions while sustaining high data packing densities by simultaneously using both orthogonal sets of conductors to address the data bits without the need for transistor switches on each conductive line. It does this by having a diode-logic addressing mechanism directly controlling the voltage levels on the conductive lines. Also, by extending the application of the diode array to perform the functions of addressing, storage, and bit sensing, symmetry is increased and this higher symmetry results in higher packing densities.

In U.S. Pat. No. 4,070,654, among others, a means is disclosed for programming the information into a semicon-

ductor diode array by selectively etching away openings through the oxide layer that insulates the plurality of doped conductors from the orthogonal plurality of metalized conductors on the surface such that each opening enabled contact between the respective conductor of each plurality thereby forming a diode representing a toggled bit of stored information at that array location. The present invention discloses a means for constructing the semiconductor device up to the final metalization etch step before programming the data thereby enabling the programming of data to be performed much later in the manufacturing process.

Mass storage devices comprising moveable media such as magnetic disks, optical compact disks, digital tape, or the like, have motors and other mechanical parts that are prone to breaking or wearing out, can suffer audio disruption when subjected to vibrations, are too heavy to be carried during certain activities such as jogging, and consume significant electrical power (due to the operation of the mechanical components). Devices utilizing ROM chips are limited in their capacities due to the limited storage densities of present day ROM chips. The present invention eliminates or reduces all of these drawbacks because it uses DRS Arrays and, as a result, has the high storage densities of a CD-ROM without having mechanical parts.

#### SUMMARY OF THE INVENTION

Instead of a CD-ROM and its associated mechanical components, this device comprises one or more Dual-addressed Rectifier Storage (DRS) Arrays which are read-only memory (ROM) devices that utilize an array of rectifiers for its storage means. Like the predecessors to the DRS Array, the logical state of stored data is determined by the presence or absence of rectifiers at the points of intersection of two orthogonal and overlapping sets of generally parallel conductive lines. The present invention uses both sets of generally parallel conductive lines for addressing but senses the logical state of the addressed data by sensing the loading on the selected lines.

The DRS Array comprises a cross-point selection means that enables the selection of a single point of intersection from within an array by applying a forward voltage across that point; this selection means will find applications in Read Only Memory (ROM) as shown in the present device, One-Time Programmable Read Only Memory (OTPROM), Random Access Memory (RAM), and LED matrix displays.

More specifically, the DRS Array comprises an array of Rectifiers (where the column lines are connected to the cathodes of said rectifiers and the row lines are connected to the anodes of said rectifiers) wherein the row lines and column lines are pulled through resistive means to either the positive supply or to ground, respectively, such that, absent any addressing circuitry, all of the rectifiers in the array would be forward biased. The addition of addressing circuitry will selectively connect those row lines and column lines to either ground or the positive supply such that the voltage potential between any row line and column line would be dropped to the point that an interconnected rectifier no longer would be forward biased. Any line whose voltage is pulled close to either ground or to the positive supply and away from that voltage that would result from the resistive means alone will be referred to as Being "disabled."

Selection of a line in both sets of generally parallel lines is accomplished by a diode addressing array similar to that disclosed in U.S. Pat. No. 4,661,927 but, instead of using diode-transistor logic (DTL) means to do this addressing, no transistor buffer-driver stage is used, thereby greatly reduc-

ing circuit complexity while eliminating a source of possible current leaks. This is possible by taking advantage of the forward voltage drop characteristics of a rectifier to control the voltage levels. The present device does not attempt to drive a heavily loaded selected line (where all of the orthogonal output lines that are connected to the selected line through diodes comprise that loading) that might require such a buffer-driver stage; the only load is that rectifier connection to the selected orthogonal line. One result of this disabling means is a greatly simplified selection circuit on both orthogonal sets in the array. The addressing means, the storage means, and the bit sensing means are all formed in the same rectifier array structure in a highly simple and symmetric design that is ideal for high packing densities.

The present invention comprises DRS Arrays that could be removable and interchangeable so that one could pop them in and out according to their current musical interest or desire. A DRS Array is expected to be able to hold the equivalent of an entire CD-ROM or more on a single one inch (or smaller) square of silicon, unlike conventional read only memory chips (ROM's) which would require about 50 ROM chip if each contained about 10 Megabytes of data. By contrast, the present invention would be very small and compact.

While most present day mass storage devices rely on such moveable media as magnetic disks, optical compact disks, digital tape or the like, the present invention, through the use of the DRS array, eliminates the mechanical components of such devices. In so doing, the present invention reduces the risk of mechanical failures, the problems of bulkiness, and the consumption of electrical power. The many possible variations on the DRS Array make it a very versatile storage medium ranging from a stand-alone array chip, to an array chip with an incorporated sequentially loaded address sequencer, to a microcomputer chip that utilizes the DRS Array for its program memory, to a personal stereo unit utilizing a removable DRS Array instead of a music CD-ROM, to a pocket sized video player utilizing a removable DRS Array module containing compressed video data.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1. illustrates a block diagram of a digital logic device comprising a Dual-addressed Rectifier Storage (DRS) Array, keypad, CD display and dual analog outputs.

FIG. 2. illustrates a schematic diagram showing one way to interface a Dual-addressed Rectifier Storage Array to a digital logic device.

FIG. 3. illustrates a schematic diagram of a Dual-addressed Rectifier Storage Array.

FIG. 4. illustrates a schematic diagram of a Dual-addressed Rectifier Storage Array which includes complementary address selection circuitry.

FIG. 5. illustrates a variation on the data sensing means of a Dual-addressed Rectifier Storage Array for simultaneously accessing multiple stored bits in parallel and a variation on the addressing means for reducing the device's power consumption.

FIG. 6. illustrates the doping step in the semiconductor manufacture of the Anode Lines, Cathode Lines, and rectifiers comprised by a Dual-addressed Rectifier Storage Array.

FIG. 7. illustrates the oxide growth step in the semiconductor manufacture of the Anode Lines, Cathode Lines, and rectifiers comprised by a Dual-addressed Rectifier Storage Array.

FIG. 8. illustrates the oxide etch step in the semiconductor Manufacture of the Anode Lines, Cathode Lines, and rectifiers comprised by a Dual-addressed Rectifier Storage Array.

FIG. 9. illustrates the metalization step in the semiconductor Manufacture of the Anode Lines, Cathode Lines, and rectifiers comprised by a Dual-addressed Rectifier Storage Array.

FIG. 10. illustrates the metalization etching step in the semiconductor manufacture of the Anode Lines, Cathode Lines, and rectifiers comprised by a Dual-addressed Rectifier Storage Array.

FIG. 11. illustrates a variation on the semiconductor manufacture of the Anode Lines, Cathode Lines, and rectifiers comprised by a Dual-addressed Rectifier Storage Array.

FIG. 12. illustrates a plot of the voltage/current relationship of a diode.

FIG. 13. illustrates a schematic diagram of a variation on the Dual-addressed Rectifier Storage Array wherein the resistive means is accomplished via "leaky" diodes.

FIG. 14. illustrates a schematic diagram of a variation on the Dual-addressed Rectifier Storage Array which includes serial addressing circuitry.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Refer now to the drawings which show a preferred embodiment of the invention. FIG. 1 shows a block diagram of a digital logic device comprising a microcomputer, a keypad, an LCD display, analog to digital converters, analog buffers and amplifiers, a headphone jack, and a Dual-addressed Rectifier Storage (DRS) Array. Microcomputer, A, is connected to a keypad, B, and an LCD display, C. This configuration is very common and several of the manufacturers of microcomputer chips have application notes showing the details and schematics of such a circuit configuration. Microcomputer, A, is also interfaced to two 16 bit digital to analog converters, E, whose outputs are connected to circuitry, F, capable of driving a set of headphones (plugged into this device at the headphone jack, G). Circuitry such as this just described is known by one skilled in the art; this circuitry exists in essentially this form in many common devices, including portable CD-ROM audio players used for listening to music CD's.

Software running in the microcomputer, A, would cause that microcomputer to sequentially read 4 bytes of data from the DRS Array, D, every 25  $\mu$ Sec and move that data to the two 16-bit digital to analog converters, E. The result of this process would be 16 bit stereo sampled at 40 KHz thereby matching the audio of current CD-ROM technology. Software running in the microcomputer could also cause information read from the DRS Array (such as musical artist, title of the audio tracks, playing time, and the like) to be displayed on the LCD display. Software running in the microcomputer could also read from the keypad to affect the operation of that running software and cause it to jump to a specific address in the DRS Array at which point it would continue to read sequentially (such as to skip or repeat certain audio tracks, play the tracks contained in the DRS Array in random order, or the like).

The data contained in the DRS Array need not be limited to musical data. Video data, computer software or applications, reference data such as text, diagrams or the like, or a variety of other information could be stored. Of course, in many of these possible data types, the exact configuration as shown in FIG. 1 may not be needed. for example, a DRS Array containing computer software would likely not need two digital to analog converters for output but would rather need interface logic such that it could be connected to a standard computer such that it emulated a

standard CD-ROM drive. In this way, one could enjoy the benefits afforded by the use of DRS arrays without having to modify one's standard computer or its software (given an accurate emulation of a CD-ROM drive, that standard computer would operate just as if it was actually connected to a CD-ROM drive). What is needed is the ability to connect DRS Arrays to such digital logic devices as a personal computer, a microprocessor, a microcomputer chip or the like.

Refer now to FIG. 2 which shows a possible way to interface a Dual-addressed Rectifier Storage Array to a digital logic device. On microprocessor, A, the address lines (or input/output ports configured to perform the function of addressing), A0 through A15, connect directly to the lower address lines, A0 through A15, of the DRS Array, as well as to the inputs of the 16 bit latch, H. The upper 16 bits of the address to the DRS Array are set by writing to a location in memory having the same lower 16 address bits as is desired for the upper address bits. When the write line, -WR, goes low and, at the end of that write cycle (when that write line goes back high), that rising edge will cause the address bits A0 through A15 to be latched in the 16 bit latch, H, where they will be held to address the upper address lines of the DRS Array, A16 through A31, until the next write cycle. Note that the data byte written is ignored, only the address bits are needed to set the latch. (A variation would be to make use of that data byte to control the selection of multiple DRS Arrays or to address additional address bits of an even larger DRS Array. Other techniques for latching additional selection bits are readily known by those skilled in the art if multiple DRS Arrays are to be interfaced. Of course, if the digital logic device was a microprocessor having an addressing port sufficiently wider than the 16 bits shown in this figure, then the latching mechanism would be unnecessary as the entire DRS Array might be addressed directly.) The DRS Array is configured to be enabled by applying power through PNP transistor, I, and resistor, J, when the read line, -RD, goes low. The DRS Array as shown in FIG. 2 would contain about 537 Megabytes of information or about 56 minutes of 16-bit stereo audio sampled at 40,000 KHz, roughly the equivalent of a present day CD-ROM.

Throughout the remainder of this description, references will made to the positions of different parts of the DRS Array; this is for ease of looking at the figures only, and is not meant to imply physical location of components in an actual device. Also in this description, transistors in the fully on state will be referred to as being saturated. Switching transistors into and out of saturation is typically slower than switching them into and out of a nearly saturated state (although nearly saturated will generally work as well). Circuitry to keep transistors from becoming fully saturated is desirable but not required and has been omitted for the purpose of keeping the descriptions and figures uncluttered.

Refer now to FIG. 3 which illustrates an example of a preferred embodiment of a Dual-addressed Rectifier Storage Array. While the array in this example is only 64 bits in size, it will become clear to one skilled in the art that this array is highly scaleable.

Rows are drawn running horizontally in this figure and Columns are drawn running vertically. The Storage Rows, P, are connected to the Row Resistors, R. Also connecting to the Storage Rows, P, at various points are the anodes of the Storage Rectifiers, K, the anodes of the Row Addressing Rectifiers, L, and the anodes of the Storage Bit Sensing Rectifiers, U. Connecting to the Addressing Columns, N, are the cathodes of the Row Addressing Rectifiers, L. Connecting to the Storage Bit Sensing Column, M, are the cathodes of the Storage Bit Sensing Rectifiers, U.

The Storage Columns, O, are connected to the Column Resistors, S. Also connecting to the Storage Columns at various points are the cathodes of the Storage Rectifiers, K, and the cathodes of the Column Addressing Rectifiers, T. Connecting to the Addressing Rows, Q, at various points are the anodes of the Column Addressing Rectifiers, T.

To understand the operation of the device, first consider what the operation of the device would be absent the row addressing means (the Row Addressing Rectifiers, L, and the Addressing columns, N) and the column addressing means (the Column addressing Rectifier, T, and the Addressing Rows, Q) and the bit sensing means (the Storage Bit Sensing Rectifiers, U, and the storage Bit Sensing Column, M). What would be left are the Storage Rows, P, which are each pulled to the positive supply through the Row Resistors, R, and the Storage Columns, O, which are each pulled to ground through the Column Resistors, S. The result would be that any rectifier present among the Storage Rectifiers, K, would be forward biased and the forward voltage drop of any said Storage rectifier would be centered around the voltage level of one-half of the positive supply (the Row Resistors, R, and the Column Resistors, S, are of equal resistance values and therefore form a voltage divider having a center voltage level of one-half of the positive supply). The resistive means, Row Resistors, R, and the Column Resistors, S, could be constructed through the use of resistors or their equivalent, the use of transistors (bipolar or FET) biased in their linear region (between being completely turned off and being saturated), the use of "leaky" diodes, or the like.

Next, consider the impact of the Row Addressing Rectifiers, L, and the Addressing Columns, N. The Addressing Columns, N, work in complementary pairs labeled by address designation  $A_n$  and its complement  $\neg A_n$  (where  $n$  indicates the  $N$ th address line). Addressing is performed by pulling an Addressing Column near to ground or near to the positive supply and its complementary Addressing Column near to the positive supply or near to ground respectively. (Allowing an Addressing Column to float instead of pulling it close to the positive supply would work, too.) When an Addressing Column is pulled near to ground, any of the Row Addressing Rectifiers whose cathodes are connected to said Addressing Column will be forward biased and the voltage drop across those rectifiers will determine the resulting voltage on the Storage Rows connected to said forward biased Row Addressing Rectifiers. Storage Rows whose voltages are pulled down in this way are called "disabled." The voltage level on said disabled Storage Rows would be equal to the near to ground voltage on the Addressing Column plus the forward voltage across said forward biased Row Addressing Rectifier.

Next, consider the impact of adding the Column Addressing rectifiers, T, and the Addressing Rows, Q. The Addressing Rows, Q, work in complementary pairs labeled by address designation  $A_n$  and its complement  $\neg A_n$  (where  $n$  indicates the  $N$ th address line). addressing is performed by pulling an Addressing Row near to ground or near to the positive supply and its complementary Addressing Row near to the positive supply or near to ground respectively. (allowing an Addressing Row to float instead of pulling it close to ground would work, too.) When an Addressing Row is pulled to the positive supply, any of the Column Addressing Rectifiers whose anodes are connected to said Addressing Row will be forward biased and the voltage drop across those rectifiers will determine the resulting voltage on the Storage Columns connected to said forward biased Column Addressing Rectifiers. Storage Columns whose voltages are pulled up in this way are called "disabled." The voltage level

on said disabled Storage Column would be equal to the near to the positive supply voltage on the Addressing Row minus the forward voltage across said forward biased Column Addressing Rectifier.

Disabling the Storage Rows by pulling their voltages down and disabling the Storage Columns by pulling their voltages up will reverse bias any Storage Rectifiers at the intersection of said disabled Storage Rows with said disabled Storage Columns. The Storage Rectifier, if any, at the intersection of the remaining enabled Storage Row with the remaining enabled Storage Column will be forward biased and the forward voltage drop of said Storage Rectifier, if any, would be centered around the voltage level of one-half of the positive supply. This would place the voltage level on the enabled Storage Row at one-half of the positive supply plus one-half of the forward voltage drop across said Storage Rectifier. Also, this would place the voltage level on the enabled Storage Column at one-half of the positive supply less one-half of the forward voltage drop across said Storage Rectifier. If no Storage Rectifier was present at the intersection of the remaining enabled Storage Row with the remaining enabled Storage Column then the voltage on that enabled Storage Row would be the positive supply and the voltage on that enabled Storage Column would be ground. (It should be noted that it does not matter if the storage rectifiers between the disabled rows and the disabled columns are forward biased because, as will be seen below, the storage bit sensing circuitry will not sense those Rows that have been shifted to the disabled voltage level.)

The Storage Bit Sensing Column, M, is to be biased to a voltage level just below the positive supply minus one rectifier forward voltage drop. Recalling that a disabled Storage Row will be at a voltage level equal to a near to ground voltage plus a rectifier's forward voltage, this means that the Storage Bit Sensing Rectifiers, U, between the Storage Bit Sensing Column, M, and each of the disabled Storage Rows will be reverse biased and conduct no current; this will account for the state of all of the Storage Bit Sensing Rectifiers, U, except the one connected between the Storage Bit Sensing Column, M, and the one enabled Storage Row. If a rectifier is present at the intersection of the enabled Storage Row with the enabled Storage Column then that enabled Storage Row, then the voltage level on that enabled Storage Row would be at one-half of the positive supply plus one-half of a rectifier's forward voltage which would not be sufficient to forward bias the Storage Bit Sensing Rectifier and no current will flow to the output, OUT. On the other hand, if no rectifier is present at the intersection of the enabled Storage Row with the enabled Storage Column then that enabled Storage Row, absent any Storage Bit Sensing Rectifier, would be at the Voltage potential of the positive supply; this is sufficient to forward bias the Storage Bit Sensing Rectifier and current will flow to the output, OUT. Naturally, this assumes that the voltage level of the positive supply is sufficiently high to forward bias the various rectifiers as described. Also, it is preferable to keep the positive supply to as low a voltage as possible in order to minimize power dissipation and to minimize the reverse voltages on the Storage Bit Sensing Rectifiers, U, thereby reducing the potential current leakage through those Storage Bit Sensing Rectifiers that might tend to offset the output current. This leakage current would be fairly constant and equal to the leakage of a rectifier reverse biased by an amount equal to the difference between the bias voltage on the output and the voltage on a disabled Storage Row multiplied by the number of disabled Storage Rows and, as such, could be corrected for if necessary. For example, an

opposite current of equal magnitude could be injected into the Storage Bit Sensing Column.

As shown in FIG. 3, to the left of each Storage Row, P, is an address designation shown as an "X" followed by some binary digits. The "X" signifies the upper address bit inputs (which control the Addressing Rows, Q,) and the binary digits signify the lower address bit inputs which control the Addressing Columns, N. As is shown, for each address bit input there are two Addressing Columns—one corresponding directly to the address bit input (labeled An) and one corresponding to the complement of that address bit input (labeled -An). Each bit position in the address designation of any Storage Row corresponds to a given address bit input and to a complementary pair of Addressing Columns. When the bit position contains a 0, a rectifier is connected between that Storage Row and the Addressing column corresponding to the complement of that address bit input. When the bit position contains a 1, a rectifier is connected between that Storage Row and the Addressing Column corresponding directly to that address bit input.

Also as shown in FIG. 3, below each Storage Column, O, is an address designation shown as some binary digits followed by an "X". The "X" signifies the lower address bit inputs (which control the addressing Rows, N) and the binary digits signify the upper address bit inputs which control the Addressing Rows, Q. As is shown, for each address bit input there are two Addressing Rows—one corresponding directly to the address bit input (labeled An) and one corresponding to the complement of that address bit input (labeled -An). Each bit position in the address designation of any Storage Column corresponds to a given address bit input and to a complementary pair of Addressing Rows. When the bit position contains a 0, a rectifier is connected between that Storage Column and the Addressing Row corresponding directly to that address bit input. When the bit position contains a 1, a rectifier is connected between that Storage Column and the Addressing Row corresponding to the complement of that address bit input.

Refer now to FIG. 4 which shows identical circuitry to that shown in FIG. 3 except for the addition of complementary address input buffer-driver circuitry, V, W, X, and Y, as well as an output driver circuit, Z. Following the addressing of one complementary pair of addressing transistors controlled by address line A2, one will see that transistors Q2 and Q4 will be turned off through resistors R10 and R12 when A2 is at a low logic state (a low enough voltage that the base emitter junctions of Q2 and Q4 are not forward biased) or floating. When transistor Q4 is turned off, transistor Q3 will be turned on by the positive supply through resistor R11. One will also see that transistors Q2 and Q4 will be turned on through resistors R10 and R12 when A2 is at a high logic state. When Transistor Q4 is turned on, it will pull away the current available at the base of Q3, dropping the voltage on the base of Q3 and thereby turning off Q3. The result is that the directly addressed Addressing column, A2, will be pulled to near ground (approximately 0.2 v) when A2 is low and Q3 is turned on (saturated), or the complementary addressed Addressing Column, -A2, will be pulled to near ground (approximately 0.2 v) when A2 is high and Q2 is turned on.

Following the addressing of another complementary pair of addressing transistors controlled by address line A3, one will see that transistors Q11 and Q12 will be turned off through resistors R19 and R20 when A3 is at a high logic state (a high enough voltage that the base emitter junctions of Q11 and Q12 are not forward biased) or floating. When transistor Q11 is turned off, transistor Q13 will be turned on

through resistor R21 to ground. One will also see that transistors Q11 and Q12 will be turned on through resistors R19 and R20 when A3 is at a low logic state. When transistor Q11 is turned on, it will cause the voltage on the base of Q13 to come within 0.2 v of the positive supply and thereby turning off Q13. The result is that the complementary addressed Addressing Row, -A3, will be pulled to within 0.2 v of the positive supply when A3 is low and Q12 is turned on, or the directly addressed Addressing Row, A3, will be pulled to within 0.2 v of the positive supply when A3 is high and Q13 is turned on.

The output driver circuit, Z, achieves the voltage biasing of the Storage Bit Sensing Column, M, while providing gain to the output current. The three rectifiers, D33, D34, and D35, serve to set the voltage on the emitter of transistor Q1 at three rectifier forward voltage drops below the positive supply. Assuming that the forward voltage drop across the base-emitter junction of transistor Q1 is the same as the forward voltage drop of the rectifiers, this would require that the base of that transistor be at a voltage level no less than two rectifier forward voltage drops below the positive supply in order for its collector to draw current, which in turn would require that the one enabled Storage Row be at a voltage level no less than one rectifier forward voltage drop below the positive supply in order for the collector of transistor Q1 to draw current. Naturally, it is not necessary that the forward voltage drop across the base-emitter junction of transistor Q1 would be the same as the forward voltage drop of the rectifiers and one skilled in the art will know of other ways to bias the Storage Bit Sensing Column.

The circuit used to describe the operation of a DRS Array and shown in FIG. 4 can be constructed using silicon diodes (such as the 1N914) for all of the rectifiers; 1 MΩ resistors for all of the Row Resistors, R, and Column Resistors, S, and for the resistor in the output driver circuit, R9; 10KΩ resistors for all of the resistors of the address input buffer-driver circuitry, V and W; 2N3904 transistors for all of the NPN transistors and 2N3906 transistors for all of the PNP transistors. The output will sink virtually no current when addressing the point of intersection of a Storage Row with a Storage Column that has a rectifier present at that point. If no rectifier is present at the addressed point of intersection, approximately 0.7 μA will flow into the base of Q1 and, assuming a current gain (β) of about 100 times for Q1, the output will therefore sink about 0.07 mA.

Some variation on this idea will be apparent. FIG. 5 shows two variations on the Dual-addressed Rectifier Storage Array. The first variation relates to the number of bits of stored information that will be retrieved at the same time. Notice that Row Addressing Rectifiers D9 through D16, transistors QZ through Q4 and resistors R10 through R12 have been removed, that transistor Q23, rectifiers D86, D87, and D88 and resistor R39 have been added, and that the Storage Bit Sensing Rectifiers have been split into two groups where the cathodes of rectifiers D5 through D8 are now connected to the base of transistor Q23 through a new Storage Bit Sensing Column. The resulting circuit is the equivalent of two DRS Arrays placed one above the other with each having four Storage Rows and eight Storage Columns where those eight Storage Columns (and their associated addressing means) are common to both arrays and where the Addressing Columns that are connected to the cathodes of the Row Addressing Rectifiers of the two arrays (and their associated addressing means) are also common to both. Transistor Q1, rectifiers D33, D34, and D35, and resistor R9 now operate with Storage Bit Sensing Rectifiers, D1, D2, D3, and D4, to detect state of the addressed bit

within one array and transistor Q23, rectifiers D86, D87, and D88, and resistor R39 now operate with Storage Bit Sensing Rectifiers, D5, D6, D7, and D8, to detect state of the addressed bit within the other array. In this way, two bits—one from one array and one from the other array—will be read out at the same time. One skilled in the art will recognize that this variation can be applied multiple times such that even larger numbers of bits can be read simultaneously.

Also shown in FIG. 5 is a variation relating to the power requirements of the device and, in particular, to limiting the current in the device to only a portion of that device thereby reducing the overall power consumption. Notice that Column Addressing Rectifiers D36 through D43, transistors Q17 through Q19 and resistors R25 through R27 have been removed, that transistors Q20, Q21 and Q22, and resistors R36, R37, and R38 have been added and that the Storage Columns have been divided into two groups where one group is connected to the collector of transistor Q20 through column Resistors R28 through R31 and the other group is connected to the collector of transistor Q21 through Column Resistors R32 through R35. Address line A4 controls transistors Q20, Q21, and Q22 such that Q20 and Q21 are a complementary pair that controls the enabling of the left four lines or the right four lines of the Storage columns. Since a Storage Column is otherwise disabled by applying a voltage to that line (through an Addressing Row and a Column addressing Rectifier) which results in a current equal to roughly the difference of the positive supply less 0.9 v divided by the Cathode Resistor value 1 M $\Omega$  (4.1  $\mu$ A if using a 5 v supply), wherever a line can be disabled by cutting off the current through the Column Resistor, that much current will be saved. These savings will become significant in much larger arrays having a very large number of Storage Columns. The limit on the number of address lines that will control this type of power reducing means for enabling Storage Columns relates to the complexity of the circuit by increasing the number of transistors (a complex component) while reducing the number of rectifiers (a relatively less complex component). One skilled in the art will recognize that this same type of power saving enabling means could also be created on the Storage Rows by using PNP transistors to control the cutting off of current to those Storage Rows (through the Row Resistors).

Another variation might be to use differently made components. For example, in the above explanation, silicon rectifiers having a forward voltage of about 0.7 v and transistors having base-emitter forward voltages also of about 0.7 v were assumed. But, other types of rectifiers and transistors could be used having lower or higher forward voltages. In another variation, the Storage Rectifiers used could be the base-emitter junctions of NPN transistors (having all of their collectors tied together in the same way one would tie together the outputs of opened-collector gates in a logical AND configuration); this would make it possible to eliminate all of the Storage Bit Sensing Rectifiers, transistor Q1, resistor R9 and rectifiers D33, D34 and D35 and instead sense the current sunk on the combined collectors. Since no more than one Storage Rectifier will be conducting at any time, current being sunk on the combined collectors would indicate that a Storage Rectifier (a base-emitter junction) exists at the point of intersection of the enabled Storage Row and the enabled Storage Column. Other variations could include, memory cells comprising a fusible link resulting in a One Time Programmable Read Only Memory (OTPROM) device (see U.S. Pat. Nos. 4,312,046 and 4,385,368), or memory cells comprising charge-storage devices to

create a Random Access Memory (RAM) device (see U.S. Pat. Nos. 3,626,389 and 3,838,405).

The above description of the preferred embodiment makes reference to a variation on the resistive means—that of using “leaky” diodes. FIG. 12 shows a plot depicting the voltage/current relationship of a typical diode, where the horizontal axis is voltage, V, and the vertical axis is current, I. Moving right from the plot’s origin, one can see that no significant current flows through the diode until the Forward Voltage, F, is reached. Moving left from the plot’s origin, one can see that only a small amount of leakage current flows until the Reverse Breakdown Voltage, R, is reached. However, there is a region, A, between the origin and the point of the Reverse Breakdown Voltage where the device behaves similarly to a resistor.

FIG. 13 shows a variation wherein the resistive means comprises diodes that are believed to operate in this resistor-like region. The diode biasing circuit, A (which would typically not be constructed as a part of an integrated circuit comprising the remainder of the circuit shown in this figure), comprises circuitry for biasing a row of diodes, H, in this resistor-like region for the row lines as well as circuitry for biasing a row of diodes, J, in this resistor-like region for the column lines. All of the diodes would be formed as a part of the same integrated circuit and would therefore have operating characteristics that are matched. On the row lines, the diodes, H, will be biased between the voltage of a disabled row and the voltage present at the output of the operational amplifier, B. The operational amplifier circuitry will ensure that the voltage across feedback diode D102 will be the same as is across the diodes, H. As a result, the current through diodes, H, and diode D102 will be the same as a result of the device matching. This is accomplished by pulling down point K in identical fashion to when pulling down any of the row address lines (A0 through A2). This ensures that the voltage on the anode of diode D103 will match the voltage on any one of the disabled row lines since an operational amplifier operates (as one skilled in the art knows) such that the same voltage will be present at the ‘+’ and ‘-’ terminals in normal feedback mode. Current sources C and D have equal magnitude and ensure that the same current flows through D102 and D103 and, therefore, that the voltage drop across D102 and D103 is matched; they could be constructed as a part of a standard current mirror circuit. The result is that the voltage at the anode of diode D102 matches the voltage on one of the disabled row lines, that the voltage on the anodes of diodes D86 through D93 matches the voltage at the anode of diode D102 (they are connected to the row lines), and the cathodes of all the diodes D86 through D93 as well as the cathode of diode D102 are at the same voltage (which is greater than that of the disabled row lines resulting in a reverse voltage across all the diodes). Given that the reverse voltage drop across diodes D86 through D93 is the same as that across diode D102, the current leaking through the diodes D36 through D93 will be the same as the current leaking through diode D102 (and controlled by current source C) due to their matched operating characteristics. The same mechanism is essentially accomplished for the column line resistive means with via operational amplifier E, current sources F and G, diodes D94 through D101, feedback diode D104 and diode D105, but with opposite polarity. Note that point L would be sourced in identical fashion to the sourcing of the column address lines (A3 through A5).

FIG. 13 also shows a possible solution should the cumulative diode leakage currents in extremely large arrays of Storage Rectifiers become noticeable. An additional



Addressing Row, N, has been included. Notice this row has a rectifier connecting it to every one of the Storage Columns and that asserting this row by pulling it to the positive supply will disable the one remaining Storage Column that had been left enabled. As a result, it is believed that one could detect the presence of a Storage Rectifier at the point of intersection of the enabled Storage Row and Storage Column even with the existence of such leakage currents by sampling the level at the output both while asserting and not asserting this Addressing Row, N. Since the presence of a Storage Rectifier will result in a loading of the one enabled Storage Row by connecting that row through the Storage Rectifier to the remaining enabled Storage Column, disabling that Storage Column would remove this loading and result in a slightly higher voltage at the Output. However, if no Storage Rectifier is present, the level at the Output should not show any significant change.

Other variations might include reversing the polarity and types of some of the components. Because of the symmetry of the DRS array, many of the techniques shown in one area of the device can be implemented in the opposite area with only a reversal of polarities. For example, one skilled in the art will recognize that the Storage Bit Sensing Rectifiers could be connected to the Storage Columns if transistor Q1 was of the PNP type, rectifiers D33, D34, and D35 were reversed in polarity and connected in series to ground instead of to the positive supply, and resistor R9 was connected to the positive supply instead of to ground; in this variation, the collector of transistor Q1 would be a current source instead of a current sink.

In another variation the means of row or column selection by disabling certain rows or columns might be used in combination with other selection means disclosed in the prior or subsequent art.

It is believed that Dual-addressed Rectifier Storage Arrays will typically be fabricated as an integrated circuit; a possible layout of the Rows, the Columns, and the rectifiers are shown in FIGS. 6 through 10 (the addressing transistors and resistors, the Row and Column Resistors, and the connection pads to the chip have been omitted for clarity—the fabrication of these devices are well known to those skilled in the art). In FIG. 6, an N-type wafer is shown to be doped with P-type channels which form the Rows. Next (FIG. 7) is shown that an oxide layer is grown and then (FIG. 8) openings corresponding to the rectifiers in the circuit are etched through that oxide layer. The data stored in the device is programmed during this step—wherever a Storage Rectifier is desired, a hole is etched through the oxide layer (it should be noted that the pattern of the openings matches the pattern of the rectifiers as drawn in FIG. 3). FIG. 9 shows the chip with an aluminum metalization layer and finally (FIG. 10) shows the result of etching that aluminum into vertical lines which form the Columns. Wherever the aluminum contacts a doped region through one of the holes in the oxide layer, a rectifier (of the type sometimes referred to as a metal-on-silicon junction type or as a Schottky Diode type) is formed. The N-type wafer substrate would be kept at the most negative voltage in the circuit thereby creating reverse biased p-n junction between the doped regions and the substrate, the result of which is to electrically isolate those generally parallel doped regions. The generally parallel metalized regions which form the Columns are electrically isolated from each other due to their being formed upon the non-conducting oxide layer (except where they contact the doped regions through the holes in the oxide layer). Where the aluminum Columns contact the P-type Rows, a metal-on-silicon junction rectifier is formed such that the current

flow (where conventional current flow is the flow of holes, that is to say, current flowing from positive voltage potential to negative voltage potential) is from the doped regions to the metalized regions when the junction is forward biased. As shown in FIG. 10, space is available for the manufacture of the addressing components and the Row and Column Resistive means at the lower left corner of the chip and around the edges.

The addressing components might also be modified when constructing a DRS Array as an integrated circuit. The pair of resistors directly connected between each address input and the bases of the two addressing transistors could be replaced by a single resistor (as shown in FIG. 3, a single resistor could do the job of resistors R10 and R12, a single resistor could do the job of resistors R13 and R15, and so on). Those transistors could be external to the integrated circuit form of the DRS Array.

A variation on the semiconductor manufacturing of a DRS Array might be to dope N-type regions into a P-type wafer thereby reversing the polarity of the metal-on-silicon junction rectifiers (the Rows and the Columns would be reversed). Another variation would spread out the Addressing Columns across the width of the chip—alternating Addressing Columns with one or more Storage Columns—instead of grouping those Addressing Columns at the left side of the chip, this will spread out those Lines carrying most of the current in the circuit thereby more evenly distributing the power dissipation across the chip (the same technique could be done with the Rows). Another variation would be to construct the device with p-n junction rectifiers or a combination on metal-on-silicon junction rectifiers and p-n junction rectifiers.

Another variation might enable programming the stored data during the metalization etching step. Referring to FIG. 11, an opening has been etched through the oxide layer at every potential Storage Rectifier location. Programming of the stored data bits is accomplished when the metalization layer is etched. In those locations where a storage Rectifier is desired, a metal connection is left during the metal etching step between the metal pad covering the opening in the oxide layer and the metal Column; where no storage Rectifier is desired, that metal connection is etched away. It is believed that this approach will enable all of the semiconductor manufacturing steps, except the final metal etching step to be performed and that wafers so made could be stored safely under the protective metalized layer. In this way, wafers could be mass produced without regard to the data to be stored in the chip.

Economic concerns may drive several other possible variations on the semiconductor manufacturing of a DRS Array. It is expected that a significant part of the cost to manufacture these devices will be in the packaging where the greater the number of electrical connections between the package and the controlling device, the greater the cost of that packaging; a package with more leads will be more expensive and more prone to mechanical failures. As a result, it is believed that steps will be taken to reduce the number of package leads needed. One skilled in the art will quickly realize the circuitry needed to implement any of the following variations. One possibility would be to address the lower address lines directly but to retain the higher address lines internally; in other words, the latch shown in FIG. 2 would be incorporated into the DRS Array integrated circuit. Another possibility would be to incorporate a shift-register where the address bits would be shifted into the device serially and retained thereby reducing the number of addressing leads to two (the shift-register serial input and the